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INVESTIGATION OF THE IMPORTANCE OF FRAME HEIGHT COMPARED TO TEST SPECIMEN HEIGHT DURING LABORATORY SOUND ABSORPTION MEASUREMENTS

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ABSTRACT

To comply with ISO 354:2003 during laboratory testing of sound absorbers, the edges of the test specimen shall be covered by a frame. The Standard states that the frame and the test specimen shall be of equal height. This is usually unproblematic, but exceptions occur, e.g., if the absorber is of uneven height or very thin.

For this paper, several reverberation room measurements have been carried out to investigate the importance of the height of the frame compared to the height of the test specimen and how critical it is that the heights match.

Two low absorbing and two high absorbing test specimens of different heights were used in the experiments, and the tests carried out in six series, one for each test specimen and two series where two test specimens of different heights were mixed.

For each series, an initial measurement was performed with a frame that was flush with the surface of the test specimen, and the results considered the true absorption coefficient of that specimen. Comparative measurements were then carried out with no frame and with frames with set height deviations compared to the test specimen.

The results will be presented in this paper.

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1. INTRODUCTION

During laboratory testing of sound absorbers, it is common to cover the edges of the test specimen with a frame to exclude edge effects from the test results. ISO 354:2003 states that the frame shall be flush with the test specimen for Type A and B mounting [1]. This is usually achievable for most typical test specimens, but it's not uncommon that a test specimen has physical properties that make it difficult.

The most common examples of this are very thin absorbers, e.g., carpets or other floor coverings, and absorbers of non-uniform height, e.g., wall absorbers that are assembled by tiles of different height or organic materials.

In the work leading to this paper, a series of measurements have been carried out with the goal of gaining a better understanding of the effects and importance of the frame. The measurements have been performed on two different materials, one relatively low absorbing and one high absorbing. The measurement results will be presented and discussed in this paper.

2. METHODOLOGY

All measurements were carried out in accordance with ISO 354:2003, with three source positions, four microphone positions per source position and three measurements per microphone position. The interrupted noise method was used for the measurements. The reverberation room has dimensions 6.65x8.0x3.76 m, which gives a volume of exactly 200 m^3, and is equipped with 14 diffusors.

Three test specimens were used to assemble the six test objects. For an overview of the test objects and the frame heights they were tested with, see Tab. 1. Test Objects 3 and 6 respectively, are shown in Fig. 1 and Fig. 2.

Table 1. An overview of the six variants and frame heights

Test Object	Material	Thickness	Surface area	Frame height [mm]								
				0	11	19	23	36	47	73	98	148
1	Wood fibre	12 mm	10.62 m^2	X	X	X	X		X			
2	Wood fibre	24 mm	10.62 m^2	X	X		X	X	X			
3	Wood fibre	12+24 mm	10.62 m^2	X	X		X		X			
4	Polyester fibre	50 mm	10.83 m^2	X				X	X	X	X	
5	Polyester fibre	2x50 mm	10.83 m^2	X						X	X	X
6	Polyester fibre	50+100 mm	10.83 m^2	X						X	X	

Figure 1. 12 and 24 mm wood fibre boards assembled together for measurement series 3.

For each test object, an initial test was performed with a frame that was flush with the surface of the test object, and the results considered the true absorption coefficient of that object. Comparative measurements were then carried out with no frame and with frames of different heights. Finally, the initial test setup was repeated as an indicator of expected minimum deviations from the initial test. For series 3 and 6, any contribution from the vertical side area not part of the perimeter was ignored.

To ensure the highest possible comparability between the tests, the same reference reverberation time was used for all measurements within a series. The climatic conditions inside the reverberation room were strictly monitored to ensure that the initial reference reverberation time measurement was sufficiently reusable.

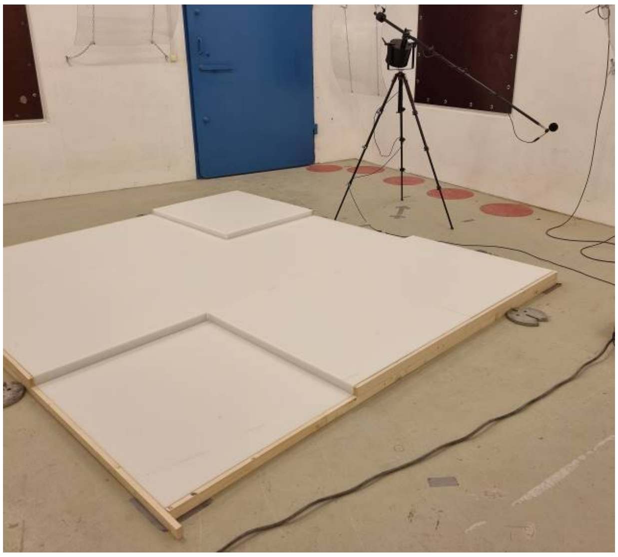

Figure 2. 50 mm polyester fibre specimens assembled into a test object with 50 and 100 mm height for measurement series 6.

After the conclusion of the tests for each series, the results were compared to the initial test and judged based on the standard uncertainty for repeatability given in ISO 12999-2 [2].

The results were also compared visually to the initial measurement, i.e., if the curve of one measurement is clearly higher or lower than the one from the initial measurement, the setup in question was deemed unsuitable regardless of whether it was within the standard uncertainty. The results were also assessed according to ISO 11654 [3].

3. RESULTS

A visual representation of the test results for the six measurement series is given in Fig. 3 through Fig. 8. In cases where some or all of the edge area is exposed, the edge area is included in the graphs.

The error bars shown represent the standard uncertainty for repeatability given by ISO 12999-2 for the results from the initial measurement.

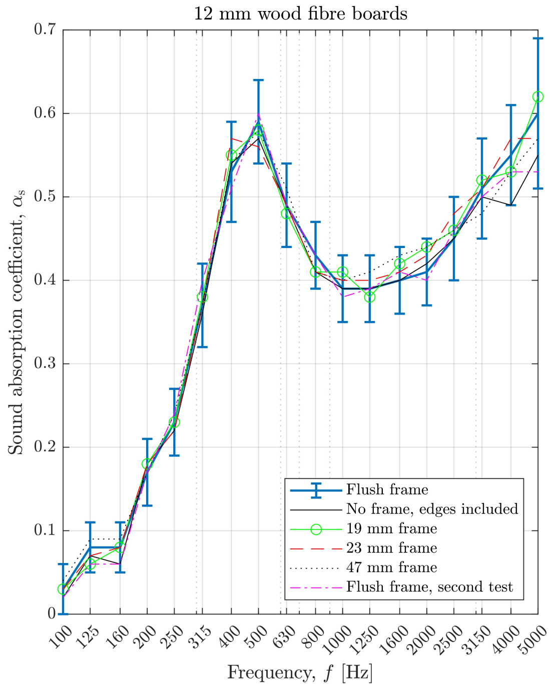

Figure 3. Measured results for Test Object 1.

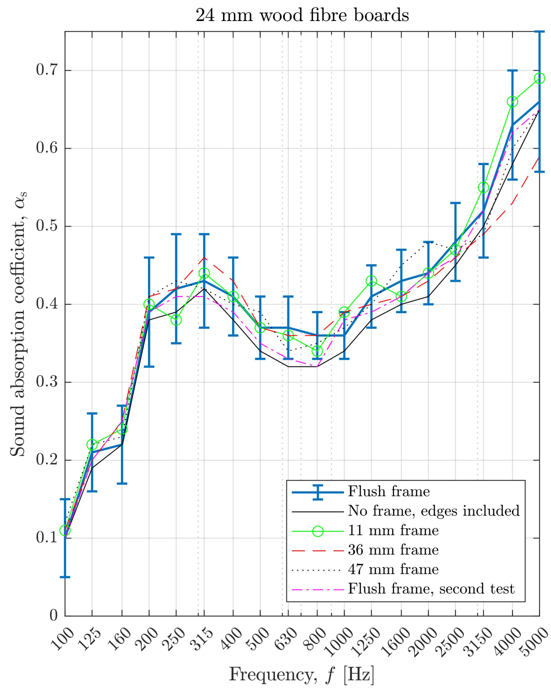

Figure 4. Measured results for Test Object 2.

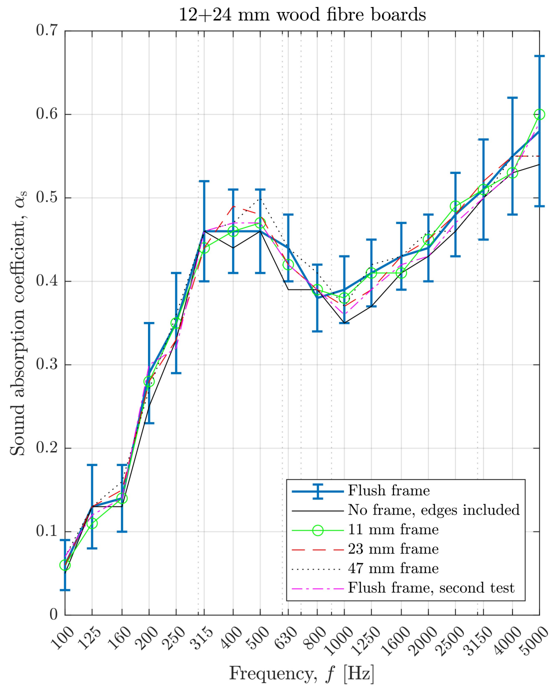

Figure 5. Measured results for Test Object 3.

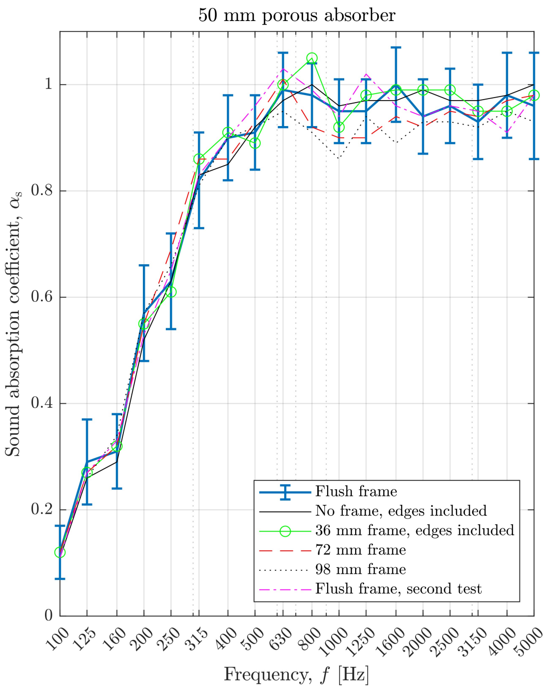

Figure 6. Measured results for Test Object 4.

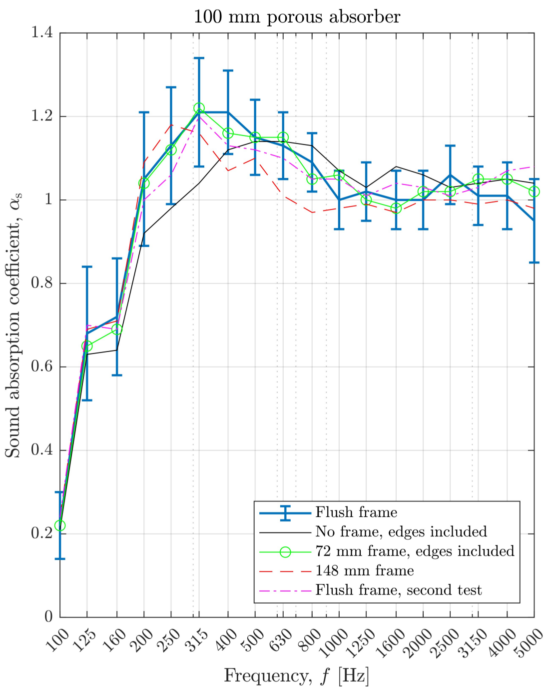

Figure 7. Measured results for Test Object 5.

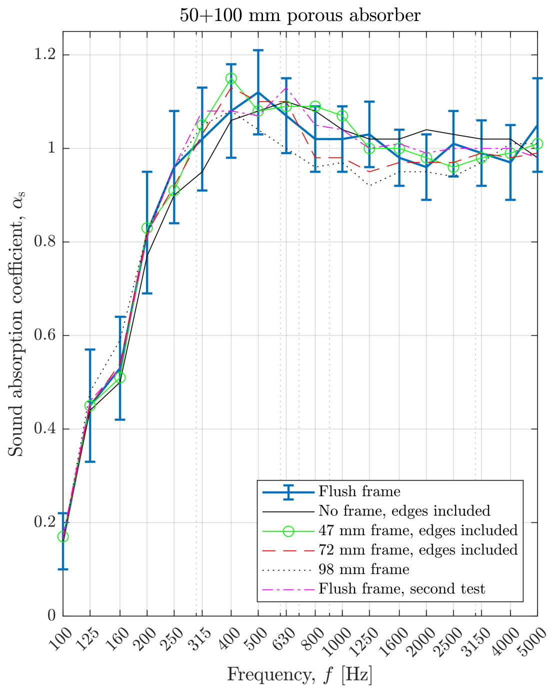

Figure 8. Measured results for Test Object 6.

4. DISCUSSION

4.1 Low absorbing materials

For the low absorbing test objects, no significant relationship between the frame height and the test specimen height was found. There are some differences between the measurements, but they are mostly within the standard uncertainty for repeatability. More importantly, there is no evident relationship between the height of the frame and the polarity of the deviations from the initial measurements.

For the thinnest test object, there was also no significant difference when measuring with no frame. The frameless measurement gave lower results in the high frequencies even when the area of the perimeter wasn't included in the calculations. This was also seen in the 24 mm wood fibre boards, where the frameless measurement yielded the lowest results of all. However, for this variant it should be noted that the repeated measurement with a flush frame gave a similar result.

As the frameless measurements generally gave lower results, in cases with test specimens that are so thin that it is practically impossible to build a frame that is flush with the specimen, a higher frame should be used rather than no frame.

4.2 High absorbing materials

4.2.1 50 mm polyester fibre

For the 50 mm porous absorber, the differences between the measurement setups were larger. There was a clear trend that the measured results worsened with increasing frame height, especially in the medium frequency range. Similarly, the measurements with a lower frame and no frame gave higher results, especially in the high frequency range.

The frameless measurement yielded a smoother curve than any of the framed measurements. When accounting for the exposed area of the edges, the results were close to the initial measurement.

The distance between the interior frame edges were 3.06 and 3.54 m, which correspond to wavelengths within the 125 and 100 Hz bands respectively. This suggests that standing waves inside the frame are having a positive impact on the measured absorption coefficient.

4.2.2 100 mm polyester fibre

The measurements on the 100 mm polyester fibre largely reproduced the findings from the previous series. With a 148 mm high frame, the results were slightly better than the initial measurement in the low frequencies, significantly worse in the medium frequencies and reasonably similar in the high frequencies.

As for the frameless measurement, the results were close to the initial measurement below 400 Hz, and significantly higher at and above 400 Hz, when the area of the edges weren't included in the calculations. With that area included, the results were quite similar at and above 400 Hz, and lower below 400 Hz. The measurement with a 72 mm frame gave results that were very close to the initial measurement when the exposed side area was included.

4.2.3 50+100 mm polyester fibre

Based on the findings above, the 50+100 mm polyester fibre test object in many ways stands out as the most challenging type of test object. In this case, large elements of 1.18 x 1.02 m were used to assemble the test object, so it was no significant challenge to build a frame that was flush with the test object, but it is easy to imagine more difficult cases.

As the measurements on the 50+100 mm polyester fibre show, a frame that is higher than the test object gives worse results in the medium and high frequency range, and no frame gives worse results in the low frequencies. Based on these findings, it is better to pick a frame that is too low rather than too high, as the exposed area of the test object can be accounted for in the results. The effects of a frame that is too high cannot be accounted for in the same way.

The measurement with a 47 mm frame, which means about 2/3 of the edge area was covered, gave results that were close to the flush frame measurements when the area of the edges was included. Interestingly, the measurements with a 72 mm frame also gave results that were close to the flush frame measurements, regardless of whether the frame was included, but compared to the 47 mm frame, the differences in the medium frequency range are quite large.

In the case of absorbers with non-uniform height, it is essential that the actual application of the absorber is kept in mind when planning the experiment. If the absorber has a high sound absorbing ability, the effects of the frame are significant, so if the absorber is meant to be mounted without a frame, it is essential that it is also tested without a frame. This is also mentioned in ISO 354, and it must be stressed that this is a conservative approach in low frequencies.

It is also not inconceivable that some designers will want their sound absorber to be mounted with a frame that *is* higher than the absorber itself. For specimens where that is the case, the test should be conducted with the frame as a part of the specimen. If the manufacturer offers a selection of various frames that go with the same sound absorbing product, the different variations should all be tested as unique products.

4.3 Assessing the repeatability

In ISO 12999-2, the standard uncertainties are highest in the low frequencies. This was, however, not the case in these measurements. Some differences occur, but they are small compared to most other frequencies, except for the frameless measurements with edges included for the high absorbing materials. The standard uncertainty for repeatability in ISO 12999-2 is derived from the standard uncertainty for reproducibility, which is notoriously high

[4], especially in the lower frequencies. Because of the vast differences between the laboratories that have participated in Inter-Laboratory Tests, it is natural that the actual standard deviation of repeatability is lower in that frequency range.

Looking strictly at the repeatability, in this case meaning the two measurements in each series that were performed with a flush frame, the deviations are largest in the medium frequency range, with small deviations in the low frequencies. In ISO 12999-2, the medium frequency range is where the lowest standard uncertainties are found. This suggests that the mounting of the frame itself is of some importance in the medium frequency range, and it seems pertinent to question the suitability of wooden frames, that are prone to crookedness which may also change over time.

4.4 Assessment according to ISO 11654

Looking at the problem in a more practical and pragmatic fashion, it is of interest to also assess the results based on ISO 11654. This standard uses 1/1 octave bands instead of 1/3 octave bands, caps the results at 1 and rounds off every number with a precision of 0,05. By converting to octave bands, some of the variations that are seen at a 1/3 octave band level even themselves out, but by rounding off, the error is prone to increase. An ISO 11654 assessment increases the importance of using a frame that is as high as or lower than the test object, because the high frame measurements often give more results below 1.

For the 100 mm porous absorber, results according to ISO 11654 were identical for all measurements where the edges were covered up. For the measurements where the edges weren't covered up, be it partially or completely, results according to ISO 11654 were identical to the initial measurement when the area of the exposed side edges *weren't* included in the calculations.

For the 50+100 mm porous absorber, a very similar trend was observed, with the only exception being the 98 mm frame, which gave lower results. The 47 mm frame gave the same results regardless of whether the area of the exposed edges was included or not. In any case, α_w was not affected. As for the 50 mm porous absorber, none of the measurements gave identical results in every 1/1 octave band, but apart from the 98 mm frame and the frameless measurement with edges included, α_w was the same for all.

The results were also generally similar for the wood fibre boards. For the 12+24 mm wood fibre board test object, only the frameless measurements gave results that deviated from the initial measurement. The results for the 12 mm wood fibre board, on the other hand, are generally deviating in the 2 kHz and 4 kHz bands, but only with a margin of 0.05. When not rounding off, the deviations are no larger than 0.02 and 0.05 in the two bands respectively.

The 24 mm wood fibre board was the test specimen where the most deviations were found when assessing the results according to ISO 11654. For this specimen, the deviations also affected α_w, and like the 50 mm porous absorber, no two measurements gave identical results in every frequency band. This was the object where the largest differences between the two flush frame experiments were observed, and it seems fair to view it as an outlier.

4.5 Frameless measurements

For the low absorbing materials, the differences between the frameless and framed measurements were quite small, but the frameless measurements generally gave lower results, even when the area of the edges were included. This was surprising, given that the reason to build a frame is to keep the edges from absorbing sound. The difference between including the edges or not weren't very big for these test specimens, as the exposed side area was very small compared to the horizontal surface area, and the sound absorbing abilities were limited also in the highest frequency range.

The porous absorbers, on the other hand, behaved more as expected. The bigger the height of the specimen, the larger the effect of the sides, and even when the side area was included, the frameless measurements generally gave higher results than the initial measurement. However, this only applies to the medium to high frequencies. In the low frequencies, a significant drop was observed. The cut off point for this effect seems to be between 315 and 400 Hz, meaning that below and at 315–400 Hz, not including the edges yield results that are closer to the true absorption coefficient of the specimen, while above 315–400 Hz, including the edges is better. This is illustrated for Test Objects 4, 5 and 6 in Fig. 9 through Fig. 11.

Although this is an interesting observation, the general results from the measurements show that not using a frame will affect the measured results significantly.

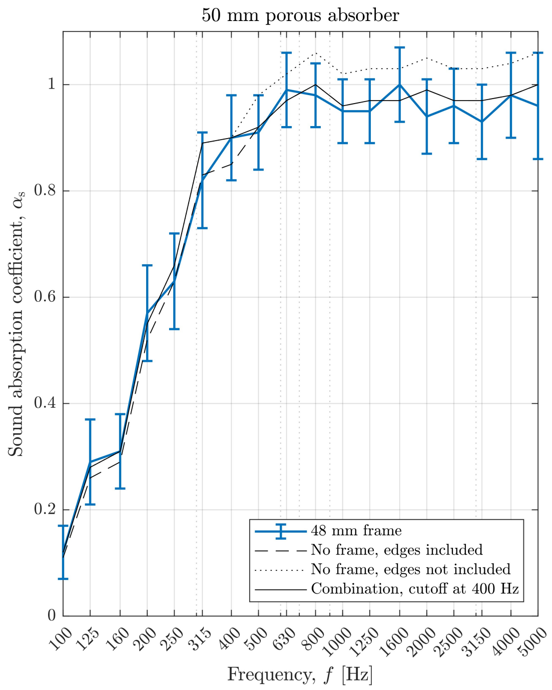

Figure 9. Frameless results for Test Object 4.

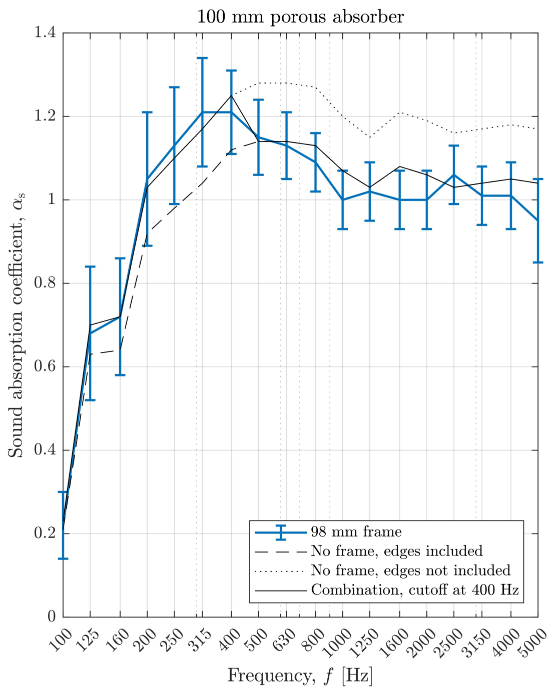

Figure 10. Frameless results for Test Object 5.

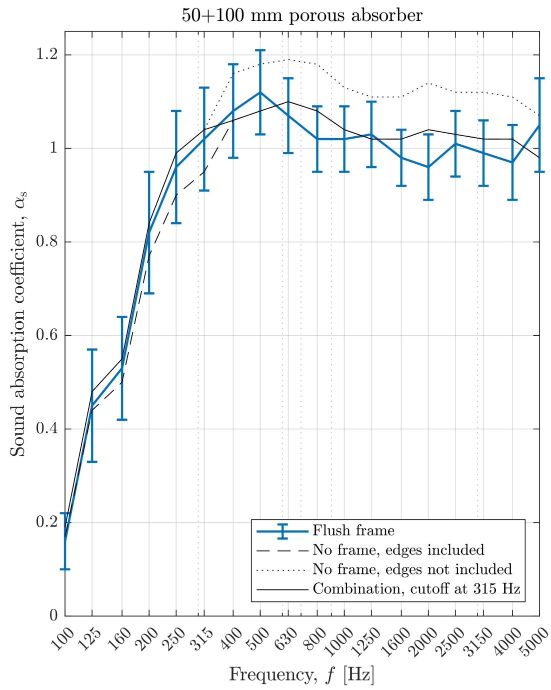

Figure 11. Frameless results for Test Object 6.

4.6 Low frequency behaviour

The height of the frame is generally only an issue in the medium to high frequency range. In the lower frequencies, a tall frame generally gives a small advantage. This is most likely due to diffraction effects. Seeing as the frameless measurements give lower results in this frequency range, it suggests that standing wave formations within the frame also play a part. If that is the case, the ratio between the sides of the test specimen, which according to ISO 354 shall be between 0.7 and 1, might affect the results in the lower frequencies. This in turn means that a ratio of 1 probably should be avoided in order to spread the modes of the frame across a wider frequency range.

This also raises the question of reproducibility in a field situation. Although the main objective of ISO 354 is to give laboratory results that can be used to compare sound absorbers against each other, the findings in this paper have shown that there are variables in play that may cause significant variations in the results. This is also mirrored in the standard uncertainties given in ISO 12999-2, which are quite large, especially in the lower frequencies.

Assuming that most practical applications for these absorbers will see them mounted from floor to ceiling, it seems that a test setup where the shortest edge is similar to the ceiling height will give the results closest to a field situation. Going by a minimum surface area of 10 m^2 and a ratio between the edges of 0.7, the minimum length of the shortest side of the specimen is 2.65 m.

4.7 Suggestions for best practice

For low to medium absorbing materials, the height of the frame is of limited importance. One should always strive to carry out a measurement in full conformity with the standard, but within a reasonable frame height of 23 to 47 mm, the end result should not be affected.

For high absorbing materials, the frame should never be higher than the test object unless it's specifically a part of the end product. Frameless measurements will also give significant deviations and should be avoided, while a frame that is around 75 % of the test specimen height is acceptable when the exposed edge area is included in the calculations. For high absorbing test specimens of non-uniform height, the frame should cover the lowest part of the specimen, and any excess side area included in the calculations.

4.8 Further work

The experiments have shown that the biggest differences between the measurements generally are found in the medium frequency range. This is visible also in the repeated tests with a flush frame and goes against the standard uncertainties given in ISO 12999-2. It would be of interest to investigate the effect of the frame itself on the repeatability and reproducibility of measurements, and how wooden and metal frames compare. Additionally, it would be interesting to compare the repeatability of those measurements to the repeatability of frameless measurements.

The findings in this paper also suggest that standing wave formations within the frame may be a contributing factor. Investigating the repeatability of different geometrical setups of the same test specimen would be of interest to determine if this is the case. If it turns out that way, that suggests that laboratory measurements may overvalue the sound absorbing ability of a specimen in the low frequencies. On the other hand, as the low frequency deviations for Inter-Laboratory Tests are so high [4], it is doubtful that any overvaluing that is due to edge effects in the low frequencies will exceed the margin for error between two laboratories.

5. CONCLUSION

A series of reverberation room measurements have been carried out to gain increased understanding of the relationship between the height of the frame and the height of the test specimen during sound absorption measurements according to ISO 354.

For low to medium absorbing materials, no significant relationship between the height of the frame and the height of the test object was found. Deviations from the initial measurement were small also when the materials were tested with no frame.

For high absorbing materials, the frame is of some importance. A frame that is too high will cause worse results and should always be avoided, while a frame that is too low will cause better results, but this can to some extent be accounted for by including the exposed side area in the calculation. Results are worse in the low frequency range when no frame is used at all.

In cases with test specimens that are of uneven height, the best course of action is to build a frame that is flush with the test object, although it is of little importance for low to medium absorbing materials. For high absorbing materials, if a flush frame is practically impossible, a frame that is around the average height of the test object is a good option.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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[2] ISO 12999-2:2020

[3] ISO 11654:1997

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